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Multiscale modelling of the induced plastic anisotropy in bcc metals

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ABSTRACT

This paper presents a new framework to predict the qualitative and quantitative variation in local plastic anisotropy due to crystallographic texture in body-centered cubic polycrystals. A multiscale model was developed to examine the contribution of mesoscopic and local microscopic behaviour to the macroscopic constitutive response of bcc metals during deformation. The model integrated a dislocation-based hardening scheme and a Taylor-based crystal plasticity formulation into the subroutine of an explicit dynamic FEM code (LS-DYNA). Numerical analyses using this model were able to predict not only correct grain rotation during deformation, but variations in plastic anisotropy due to initial crystallographic orientation. Optimal results were obtained when $\{110\}\langle 111\rangle$, $\{112\}\langle 111\rangle$, and $\{123\}\langle 111\rangle$ slip systems were considered to be potentially active. The predicted material heterogeneity can be utilised for research involving any texture-dependent work hardening behaviour, such as surface roughening.

1. Introduction

In recent years considerable effort has been made to develop accurate numerical models to predict sheet metal forming behaviour for complex loading scenarios (Roters et al., 2010). The challenges facing modellers are great: discretisation issues related to relatively small through-thickness dimensions, localisation issues such as shear-band formation, and verification issues due to complexities in experimental data acquisition (e.g. through-thickness strain readings) are some of the most formidable problems at hand (Dawson et al., 2003). The predictive capability of these models continues to improve however, particularly in the field of multiscale modelling where the physics of deformation (as outlined by Curtin and Miller (2003) and Arsenlis et al. (2004)) are incorporated into numerical analyses involving continuum mechanics (as proposed by Zienkiewicz (1967)) for a host of engineering applications. Much of the multiscale modelling studies of sheet metal forming have focused on optimisation of material flow (as in the earing studies of Zhao et al. (2004) and Raabe et al. (2005)), and predicting elastic spring-back and post-forming material shape (Kraska et al., 2009).

One example illustrating the potential application of a general-purpose multiscale model deals with the evolution of surface roughness as a function of applied strain. Decades of research concerning the ridging behaviour found in ferritic stainless steel have led to conclusions applicable to a variety of sheet metals; of note, macroscopic surface roughening can be directly related to the crystallographic texture of the material (Chao, 1967; Takechi et al., 1967; Wright, 1972). The texture – in many cases, comprising bands or clusters of similarly oriented grains – has been shown to also contribute to heterogeneous deformation within the material due to texture-specific differences in work hardening (Chao, 1967). Of particular interest is the modelling work of Becker (1998) and the experimental studies of Raabe et al. (2003), which infer that the use of a crystal plasticity finite element model that accounts for spatially resolved microtexture can determine

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